CHAPTER 1

Managing Effects of Drought: Introduction and Definition of Key Terms and Concepts

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In the most basic terms, drought is a lack of water. A place can be dry (e.g., a desert) or wet (e.g., a rain forest), but droughts can occur in both dry and wet locations as events in time. The consistently dry seasons experienced in many parts of the United States (e.g., the dry summers of much of the Western United States) would not merit the designation of "drought" per se; however, interannual variation in the duration and magnitude of dry periods can affect forests and rangelands (Seneviratne et al. 2012, Wilhite and Buchanan-Smith 2005). Therefore, particularly long dry periods within times of the year that are normally dry would be designated as drought. Drought has shaped ecological processes and influenced human and biological communities throughout the millennia and will continue to do so. It is an important disturbance process for the ecology of forests and rangelands, so is not "bad" in and of itself, but changing drought regimes present challenges for ecological communities and land managers.

Although it is difficult to quantitatively project how climate change will influence future drought characteristics (i.e., frequency, severity, timing), many global climate models project that some regions of the United States will experience a higher frequency of severe droughts and longer dry periods (IPCC 2014, Wuebbles et al. 2017) (chapter 2). Even if current drought regimes remain unchanged, higher temperatures interact with drought to exacerbate moisture limitation and water stress (Adams et al. 2009, Breshears et al. 2005).

Recent observations of regional-scale drought impacts, and expectations of more frequent and severe droughts in the future across many areas of the United States, prompted a state-of-the-science synthesis (Vose et al. 2016a) that provides a foundation for how future droughts may affect forest and rangeland ecosystems. The purpose of the current volume is to build on that synthesis and provide region-specific adaptation options for natural resource managers to increase resilience to drought, thus minimizing impacts and facilitating recovery after droughts occur.

GOALS OF FOREST MANAGEMENT

There is a long history of active forest and grassland management in the United States. Among the primary goals of management is to sustain or enhance the quality and quantity of ecosystem services provided by forests and rangelands. In the early 20th century, education and training of resource professionals were critical to meeting the needs of the Nation to restore degraded forest lands in the Eastern United States following a period of resource extraction and poor logging practices. Indeed, a primary objective of early forest management was improvement of watershed conditions for sustaining water quality and supply, including mitigation of drought (Zon 1927). The ability to successfully restore and sustainably manage forests and grasslands in the United States is evident by the contribution of both sectors to the national and global economy. For example, the timber products industry is directly responsible for 1.2 million U.S. jobs and over $72 billion in labor income; economic activity associated with the forest sector generates an additional 4 million jobs with $210 billion of associated labor income (Prestemon et al. 2016).

In addition to the value of wood products, U.S. forests and rangelands provide many ecosystem services that are difficult to quantify in economic terms but are nonetheless important. Examples include recreation, clean water, wildlife habitat, biodiversity, and climate mitigation. Forest and rangeland systems are inherently resilient to environmental stressors and disturbances, although that resilience has limits (McDowell et al. 2016), so the ability to achieve these management goals will be challenged by changing environmental conditions such as drought. Our expectation is that a better understanding of drought effects and implications for forest and rangeland values will help land managers anticipate responses and inform management actions that increase adaptive capacity to current and future drought (chapter 10).

DROUGHT AS A DRIVER OF ECOLOGICAL PROCESSES

Forest and rangeland biota already have some level of adaptive capacity to periods of dry conditions. A key unknown is whether current species in a given location and associated ecosystem processes will be able to endure more severe (or different) droughts in the future (Clark et al. 2016, Schlesinger et al. 2016, Vose et al. 2016a). Understanding adaptive traits of species and ecosystems is an important component of developing management options. Long-term studies (e.g., plot re-measurements and dendrochronology) provide strong evidence for evaluating responses to drought at the individual-species level, and more recent physiological studies provide a mechanistic basis for understanding species differences in drought sensitivity (McDowell et al. 2016).

As leaves become drier due to a lack of available moisture in the soil to rewet them at night, stomata will close when the evaporative demand of the air (a function of warm temperatures and low humidity) becomes too high. When stomata close, plants are unable to fix carbon dioxide, leading to metabolic stress. Under severe water stress, hydraulic failure can occur, interrupting the flow of water up the stem to the leaves (McDowell et al. 2016). Such failures can be partially repaired by plants, but much of the damage can be permanent.

In addition, species differ in their allocation to roots, mycorrhizal associations, and xylem anatomy, contributing to varied drought tolerance among species (Mackay et al. 2015, McDowell et al. 2016, Phillips et al. 2016). This ecological and physiological knowledge underpins science-based management of forests and rangelands in response to current and future drought regimes. Furthermore, recent large-scale tree mortality events in response to drought, drought plus elevated temperatures ("hot drought"), and drought-mediated insect outbreaks and wildfires suggest that shifting drought characteristics are altering forest structure and function at broad scales, with negative impacts on ecosystem services (Vose et al. 2016a; chapter 4).

Drought conditions cause browning on leaves of this flowering dogwood (*Cornus florida* L.). (Photo by John Ruter, University of Georgia, Bugwood.org)

ECOLOGICAL DROUGHT AS A COMPONENT OF STRESS COMPLEXES

As noted above, drought effects rarely occur in isolation from other disturbances and stressors. Insects and invasive species capitalize on drought stress in trees, which can lead to forest mortality (Breshears et al. 2005; chapters 3, 4, 6, 9). Severe moisture stress reduces both chemical and physical defenses of trees to insects, and droughts are often precursors to severe outbreaks (Creeden et al. 2014, Kolb et al. 2016, Raffa et al. 2008). Insects also benefit from the increased nutritional content of drought-stressed trees, making both defoliating and boring insect outbreaks more potent during drought conditions. Some fungal infections may be hampered by drier conditions, although many species may benefit from drought-related damage after moist conditions return. Insect attacks and fungal pathogens can further impair plant defenses against drought mortality. Prolonged and severe moisture stress can ultimately have negative feedbacks on insect populations simply through reduced food production and quality.

The spatial extent of wildfires is higher during years with extended drought (Heyerdahl et al. 2008, Morgan et al. 2008; chapters 3, 4, 6, 9), and multiple meteorological drought indices offer some predictive capability for area burned by fire at short time scales (days to months). Drought can, inversely, limit the amount of fuels, particularly in more arid locations, creating an outcome in which wet conditions preceding the dry season are associated with a larger extent of fire (Abatzoglou and Kolden 2013; Littell et al. 2009, 2018). Forest fires that occur in moist years tend to be less widespread (in part because they are easier to control), and severity patterns in these fires are controlled by topographic factors affecting soil moisture distributions (Dillon et al. 2011).

However, fires are more likely to escape control during drought years, leading to greater area burned. Although the fractional area of high severity is similar between drought and non-drought years, severity patterns show greater continuity and less discrimination based on topography in drought years. In other words, in the worst fire years, local "fire refugia" like north-facing slopes or riparian areas tend to have high-severity burns just like the surrounding hillsides, and low-severity burning tends to occur around the edges of the fire or in large patches where the fire burned in cooler or moister conditions (e.g., during the night). Land management and fire management activities that affect fuel loading can influence the spread and severity of fires (chapter 10).

Cheatgrass (*Bromus tectorum*) infestation reduces habitat quality for both vegetation and animals. (Photo by Chris Evans, University of Illinois, Bugwood.org)

Invasive species create challenges for forest and rangeland plant and animal species, often reducing ecosystem services (e.g., biodiversity, carbon storage), and drought can increase invasion success for some species and locations (chapter 5). For example, the spread of cheatgrass (*Bromus tectorum*) and other nonnative annual plants into shrub-steppe ecosystems has reduced dominance by sagebrush (*Artemisia* spp.) and reduced habitat quality for both vegetation and animals (e.g., greater sage-grouse [*Centrocercus urophasianus*]) (chapters 6, 7). Cheatgrass and sagebrush are both well adapted to frequent drought, but cheatgrass is adapted to frequent fire disturbances and sagebrush is not.

CHARACTERIZING ECOLOGICAL DROUGHT

Drought has generally been framed into four classes (Wilhite and Glantz 1985)—**meteorological drought**, **hydrological drought**, **agricultural drought**, and **socioeconomic drought**—which address periods of dry weather that negatively affect a particular resource or sector. More recent efforts address **ecological drought**, a similar concept focused on ecosystem responses. These classes are not mutually independent, but refer to different ways to measure, identify, or conceptualize drought conditions. Most types of drought are associated with meteorological conditions that result in a lack of water, such as a low precipitation or excess demand from evapotranspiration (ET).

Meteorological drought definitions refer to atmospheric components of the water balance, between precipitation and ET, where low precipitation and high evapotranspirative demand lead to a relative lack of water (chapter 2). **Hydrological**, **agricultural**, and **socioeconomic drought** are filters placed on meteorological drought to frame how they affect human demands and values for water, including food production, electrical power production, recreation, and wildlife conservation.

Ecological drought relates to the negative impacts of meteorological drought on ecosystem services. The effects of dry conditions on ecological processes often include tradeoffs, however, and some biota benefit from drought primarily because other biota are more negatively impacted. Interrupting normal drought-related disturbances can actually harm some ecosystems and reduce their resilience to future drought, as exemplified by fire exclusion in dry forest ecosystems in the Western United States (chapters 3, 4, 6). Nevertheless, evolving drought conditions can be so atypical in terms of characteristics or context that it is useful to frame **ecological droughts** as those that are outside of conditions for which current vegetation is adapted. The focus of **ecological drought** is generally on observable changes such as large-scale forest mortality, but less observable responses (such as slower tree growth or altered species composition) can have observable changes (and economic consequences) over the long term.

Key drought characteristics that drive ecological responses to drought are:

- **Severity** (defined as degree of moisture deficit)
- **Frequency** of a given level of deficit
- **Temporal patchiness** (duration and short-term variability)
- **Spatial coherence** (spatial distribution across the landscape)

The most direct measures of drought **severity** for terrestrial and aquatic ecosystems are measures such as soil moisture, streamflow, and fuel moisture, which express spatial and temporal integration of precipitation and ET. The **frequency** of a given level of drought severity is critical for understanding the ecological role of drought because the relationship of the frequency of mortality-inducing drought to regeneration or recovery times is a fundamental descriptor of ecosystem dynamics. At one end of the spectrum, species that mature more slowly than the frequency at which mortality-inducing weather events occur may not be well adapted to the local climate. At the other end of the spectrum, species that take advantage of frequent disturbance may not compete well with species that are more competitive when disturbance is infrequent.

Relationships between **frequency** and **severity** are commonly embedded within adaptations to drought and disturbance. For example, it is unusual for severe wildfire or insect outbreaks to occur frequently (e.g., every few years) because it is difficult to regrow sufficient vegetation (fuel or food, depending on the disturbance) to sustain the next severe event. The role of high-frequency, low-severity fire in thick-barked ponderosa pine (*Pinus ponderosa*) stands in maintaining low fuel connectivity is a well understood adaptation in drought-prone (and fire-prone) forests (chapters 3, 4, 6). Similarly slow-growing trees adapted to arid sites (e.g., bristlecone pine [*Pinus longaeva*]) are another example of how isolation created by frequent drought builds a degree of resilience to disease, insects, and fire spread.

Temporal patchiness describes drought duration and variability, such as the contrasts between multiple consistently dry years versus alternating wet and dry years (or growing seasons), or a long sequence of dry days. Both ends of this spectrum can have substantial effects on ecological processes and disturbance regimes. For example, high contrasts in moisture over relatively short (seasonal to interannual) time scales can increase the severity of drought-related stressors such as wildfire and insects (chapters 8, 9). This was previously noted for how wet winters and springs promote heavy growth of annual grasses, leading to more severe and larger fires during the following dry summer in shrublands (Abatzoglou and Kolden 2011, Littell et al. 2009). Substantial growth in a forest in a wet year contrasted to dry conditions the next year can lead to increased moisture stress because of increased leaf area, along with greater food abundance for defoliating insects. Exceptionally long dry periods can cause stress and in some cases mortality, even in long-lived trees.

Severe meteorological droughts with large **spatial coherence** (i.e., they occur over large spatial scales) are sometimes termed "megadroughts" because they may encompass multiple regions of the United States at a given time (Coats et al. 2014, Cook et al. 2014). Drought at this scale can potentially affect fire suppression strategies or response to insect outbreaks, although smaller spatial scales are also relevant because a particular drought may have different effects on different landscapes (e.g., north versus south aspect, side slope versus valley).

COMMON DROUGHT METRICS

Drought severity and duration are connected because the longer a place goes without rain, the greater the opportunity for ET to continue to dry the soil. Although the several dimensions of drought are important to consider for strategically managing landscapes for drought, several duration-severity metrics are commonly used to describe droughts as they progress in time and can be used to inform responses to developing or ongoing drought (chapter 2). Three of the most common metrics used to characterize meteorological drought are the Standardized Precipitation Index (SPI) (McKee et al. 1993), Palmer Drought Severity Index (PDSI) (Palmer 1965), and Keetch-Byram Drought Index (KBDI) (Keetch and Byram 1968).

The SPI is a relatively simple approach to characterizing drought, in which an anomaly occurs when the amount of precipitation (in this case, lower precipitation) differs (determined as a Z-score, or number of standard deviations above or below the mean) from the long-term mean for a specific location (McKee et al. 1993). The index is applicable only at a local scale, relative to mean precipitation over the period of interest.

The PDSI is related to water balance (difference between incoming precipitation and ET) of a relatively thin, two-layer soil incorporating estimates of evaporation and runoff. The precipitation component is relatively straightforward, and runoff is computed based on the water-holding capacity of the soil column (porosity at field capacity). Evapotranspiration is drawn from the two layers of soil independently, with the thin top layer being available for direct evaporation, while the second soil layer retains water for transpiration. Evapotranspiration is calculated based on air temperature using the Thornthwaite method (Thornthwaite 1948). Because drier soils evapotranspire less than moist soils, a seasonal

Forest (wetter sites) and rangeland (drier sites) are juxtaposed in the Blue Mountains, Oregon. (Photo by Dave Powell, USDA Forest Service [retired], Bugwood.org)

Shortleaf pine (*Pinus echinata*) is resistant to wildfire, pests, and disease. (Photo by Chris Evans, University of Illinois, Bugwood.org)

adjustment to the Thornthwaite estimate is used for well-watered soils. Derivations of the PDSI include computing ET with the Penman-Monteith (Monteith 1965) equation, which improves ET estimates under some conditions.

The KBDI (Keetch and Byram 1968) is absolute in nature and not locally indexed. It is based on an exponential decay conceptualization of soil moisture in fuels. Precipitation minus interception (constant) rewets fuels, and daily loss is calculated (in tables) as a function of the daily air temperature and the previous day's drought index. As the index approaches its driest extreme, the effect of further drying is diminished asymptotically.

The use of these metrics in real-time decision making is aided by the fact that they have been used in resource management for decades, so many land managers have become familiar with what a particular value might mean for affected resources in a given location (e.g., U.S. Drought Monitor; https://droughtmonitor.unl.edu). Unfortunately, the physical basis for some metrics limits their utility as measures of future drought, particularly those that do not use an energy balance approach for estimating ET (Milly and Dunne 2017). However, the dimensions of drought listed above (e.g., frequency, duration, severity), along with an overall warming context, frame a thoughtful approach for considering future drought challenges that is not constrained by the limitations of individual metrics (Abatzoglou and Kolden 2011, Luce et al. 2016).

ECONOMIC CONSEQUENCES OF DROUGHT

Droughts can have substantial impacts on the economy. Most obvious are droughts that reduce local, national, and global food and water supplies. The timber products industry, which represents 2 percent of the U.S. economy (Prestemon et al. 2016), can be affected by drought-related mortality and reduced productivity, leading to reduced wood supply and a corresponding increase in market price. Market-scale effects will be more pronounced when larger areas are affected by drought. The timber products industry can be a much bigger player in local, often rural economies, and disruptions in wood supply reduce employment, income, and the economic base of such locales. Frequent wood supply interruptions in an area can lead to disinvestment of milling infrastructure (Insley and Lei 2007, Sims 2011), leading to more persistent economic consequences in rural communities.

Drought in rangelands reduces forage and water available for livestock grazing and reduces overall vegetative land cover, which can lead to soil loss from wind and water erosion with long-term effects on rangeland productivity (Finch et al. 2016; chapters 3, 6, 7). Because animal stocking rates are generally determined by expected precipitation, degradation can occur quickly if drought occurs and grazing persists. Although soil conservation practices and modern irrigation have reduced the impact of episodic droughts, the effects of severe drought are a significant concern in communities where livestock grazing contributes to the local economy (Prestemon et al. 2016).

Forest and rangeland ecosystems also help regulate water supply by stabilizing surface flow (i.e., reducing streamflow extremes) and allowing more subsurface recharge (chapters 3, 6, 7, 8). In addition to the direct effects of reduced streamflow and groundwater recharge during drought, lower growth and mortality of vegetation may occur. Extensive mortality may increase overall streamflow after the drought ends (Vose et al. 2016b), although that response is not a certainty (e.g., Adams et al. 2012). Altered water quantity following drought may have little impact on economics, although degraded water quality after disturbances like fire can substantially disrupt municipal water supply and treatment in ways that may force substantial public investment in water infrastructure to avoid supply interruptions (Emelko et al. 2011).

Forest and rangeland management is greatly affected by drought, perhaps most acutely in management of wildfires. Spatially and temporally extensive droughts in the Western United States are a likely contributor to a recent (since around 1980) increase in area burned by wildfire in dry forests (Abatzoglou and Kolden 2013, Holden et al. 2018, Westerling et al. 2003). Larger and more frequent wildfires have become difficult to suppress (Stavros et al. 2014, Yang et al. 2015), resulting in higher suppression costs (Prestemon et al. 2008). The cost of fire suppression has also been partially driven by the high cost of protecting property in the wildland-urban interface.

ADAPTING TO DROUGHT

What is Adaptation?

Adaptation is an ecological term that implies a "natural" adjustment in forest and rangeland ecosystems in response to environmental stressors and disturbances. For drought, adaptation management is the purposeful implementation of management actions to minimize drought impacts, enhance recovery after drought, or facilitate transitions of ecosystems to conditions better suited to survive future droughts (chapters 3, 4, 5, 6, 7, 8, 9). The concept of using adaptation strategies to sustainably manage forests and rangelands is not new to land managers. Climatic variability and associated disturbances have challenged managers to continuously adapt management actions to adjust to changing environmental conditions, changing societal demands, and unanticipated stressors such as invasive species. It is likely that all ecosystems will experience drought at one time or another, and the likelihood of increasing drought occurrence and severity in some regions of the United States suggests that drought exposure will become more frequent and more damaging for some ecosystems.

In areas where droughts are relatively frequent, ecosystems have adjusted "naturally" with physiological and morphological adaptive measures that impart some level of resistance to drought. Examples include lower plant density, higher proportion of species with low water requirements, species with leaf traits that prevent desiccation, deep rooting, and fire-resistant characteristics in fire-prone locations. In contrast, species adapted to wetter environments may be more vulnerable to drought because they have developed adaptive traits that prioritize competitive growth over water conservation, and hence they may have a limited capacity to adapt to increasingly droughty conditions. In either case, extreme and perhaps unprecedented droughts, defined in the context of geographically specific climate regimes, may have substantial impacts on the structure and function of forest and rangeland ecosystems.

Historical and current biophysical context is an important factor in evaluating risks to future droughts and can constrain (or increase) potential adaptation options. In addition, successful and sustainable drought adaptation actions require understanding which ecosystem characteristics provide resilience to drought and which characteristics decrease resilience. In some cases, past management has decreased drought resilience. For example, fire exclusion in ponderosa pine forests has resulted in higher stand densities and fuel loadings, making these forests more vulnerable to wildfire and insect outbreaks than in much of their past history (Agee and Skinner 2005; chapters 3, 4, 6).

Cold-water fish species in the West have some degree of drought resilience because streams affected by post-fire debris flows or desiccated channels can be repopulated by migratory members of the population, providing an advantage over non-migratory species (Dunham et al. 2003, Rieman and Clayton 1997; chapters 3, 6). Land managers are learning how to augment rather than hamper natural drought adaptations, thus acknowledging the dynamic nature of ecosystems (e.g., Penaluna et al. 2018).

Resistance, Resilience, and Response Options to Facilitate Transitions

Millar et al. (2007) proposed three primary adaptive strategies in response to climatic variability and change: increase resistance, increase resilience, and facilitate transitions. **Resistance options** are intended to create ecosystem conditions that are better able to resist change and therefore **minimize impacts**. For drought, examples may include management efforts to prevent drought-mediated disturbances such as insect outbreaks and wildfires. Options include reducing stand density with thinning to maintain lower fuel loads and increase overall tree health and vigor (chapters 3, 4, 6, 9).

Resilience options are intended to promote a return to a prior condition following disturbance, thus **facilitating recovery**. For drought, examples include favoring (through planting or selective cutting) species that are more drought tolerant, and creating and maintaining high species and structural diversity. Thinning and harvest that break up fuel (for fire) and food (for insects) continuity (Hessburg et al. 2015, Logan and Powell 2001) reduce spread during events and encourage smaller patches that are more easily seeded by surviving vegetation.

Response options designed to **facilitate transitions** move the ecosystem from current to new conditions, in **anticipation** of creating ecosystem structure and functions that are better adapted to **future conditions**. Examples include preferentially planting drought-tolerant species or genotypes in areas where drought is expected to worsen.

Resistance options are intended primarily as a short-term strategy in a warming climate, whereas resilience can be effective for longer time scales, and transition response options are long-term strategies once neither resistance nor recovery is an available option. These different options should not be considered mutually exclusive; for example, some resistance management actions may also impart resilience (and vice versa), and transformation of some areas or aspects of an ecosystem may allow persistence of others for a longer period.

The Maintain-Repair-Engineer Spectrum

Although there are broad goals of resistance, resilience, or transitioning, Rieman et al. (2010) argue that the choices in the landscape range from (1) a largely passive role in maintaining an already resilient/resistant ecosystem (transitioning on its own), to (2) restoring/repairing an area in the direction of resilient/resistant condition or toward a transition, to (3) aggressive management of conditions and outcomes in order to actively provide resilience/resistance or transition. This spectrum is primarily about level of effort and sustainability given a large expanse of forests and rangelands, but it has other implications as well. Wilderness and surrounding remote areas with mostly passive management are examples of places where extensive intervention is not feasible, and in some cases, less important to maintain functions and processes that provide desired ecosystem services.

At the other end of the spectrum are places where natural dynamics associated with drought could pose a hazard to isolated populations of rare biota or places of human habitation, requiring intensive and ongoing management efforts to substitute for natural dynamics that sustain particular conditions. Between these extremes are places that might require some short-term management effort to facilitate conditions that have long-term resilience. Different forests have different pathways through which they have arrived to current circumstances. Some forests have been so altered by historical management (or lack thereof) or by altered land use (e.g., residential construction) that intervention is now necessary (e.g., establishment of longleaf pine [*Pinus palustris*] forests) (chapters 5, 9). Other forests may only recently have begun to show reduced health due to shifts in climate.

In this framework, desirable landscape conditions are relatively resilient to natural and evolving dynamics driven by drought. At the same time, there is an acknowledgment that the specific values to be maintained or protected need to be directly identified, whether they be genetic diversity, ecosystem function, or some economic provisioning service. Do we need to protect species or populations? Are we looking simply for a forest ecosystem, even if it is a new mix of species? How much effort can we afford to meet these goals? Ultimately, any efforts at resilience and resistance for a given landscape will need to yield to some transition, and decisions need to be made about (1) which values and conditions are critical and (2) the costs and benefits of management interventions to sustain those values and conditions. It will likely be easier to maintain resilience for "a forest" than for a forest with a particular distribution and abundance of species (chapter 10).

Doing Things Versus Learning Things

Although much is known about options for managing forests and rangelands in response to current and anticipated drought, there is still a high level of uncertainty, and surprises are likely. This uncertainty suggests a need for monitoring and ongoing learning to adjust management actions and goals over time. Specifically, effective management requires that managers are an intelligent component of the ecosystem who are able to learn and use information on trends and responses to disturbance, anticipating future conditions and developing robust management decisions over time (chapter 10). This is especially challenging because changing drought regimes may create conditions that are different than those observed at any time in the past. The ability to anticipate responses, and to change course if anticipated responses do not occur, will be critical for effectively sustaining ecosystem services.

Being informed enough to take effective action requires a combination of (1) ongoing monitoring to track what affects timely decisions (e.g., being ready to prepare a postdrought recovery action in a timely way), (2) monitoring that can detect the success or failure of previous plans, and (3) active experiments that anticipate that one idea will work but others will fail (chapter 10). If we look at adaptation in a Darwinian sense, no species is already adapted to new conditions, and it is the populations and genes that can cope with evolving conditions that are ultimately successful—in other words, those that can **learn**.

The following chapters in this volume provide regionally specific management options for minimizing drought impacts, facilitating postdrought recovery, and managing in anticipation of future drought conditions based on current knowledge. The intent is to provide general guidance for land managers to combine with their local knowledge, experiences, management objectives, and current constraints. In most cases, species, ecosystems, and human communities will likely be best served by a full range of management intensities, from intensive management responses to "observe, evaluate, and respond." Learning strategies will hopefully range from **thoughtful management**, in which management options are implemented and management actions are modified based on observed responses, to **adaptive management** (*sensu* Walters 1986) in which experimental management is applied with rigorous modeling and monitoring.

Drought damage. (Photo by Petr Kapitola, Central Institute for Supervising and Testing in Agriculture, Bugwood.org)

PURPOSE AND APPROACH FOR REGIONAL CHAPTERS

The purpose of this report is to inform and guide natural resource managers as they evaluate management options to minimize drought impacts, help forests and rangelands recover from drought, and create forests and rangelands better adapted to future drought conditions. An overall conceptual framework and development of organizational structure and chapter content were facilitated by a series of virtual and in-person workshops. Teams of experts used a national-scale drought synthesis (Vose et al. 2016a), combined with more recent scientific literature and their best professional judgments, to link scientific evidence with regionally appropriate discussions of risks, vulnerabilities, and management options.

Chapter 2 describes projections of potential changes in drought in the United States as a frame of reference. The remaining chapters are organized by regions: Alaska and Pacific Northwest (chapter 3), California (chapter 4), Hawai'i and U.S.-Affiliated Pacific Islands (chapter 5), Interior West (chapter 6), Great Plains (chapter 7), Midwest and Northeast (chapter 8), and Southeast (chapter 9). Authors were provided a general framework and guidelines for writing but retained flexibility to organize and develop chapters to address key issues and challenges specific to each region.

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